Long Term Ground Deformation in Volcanic Islands: Tenerife and La Palma, Canaries

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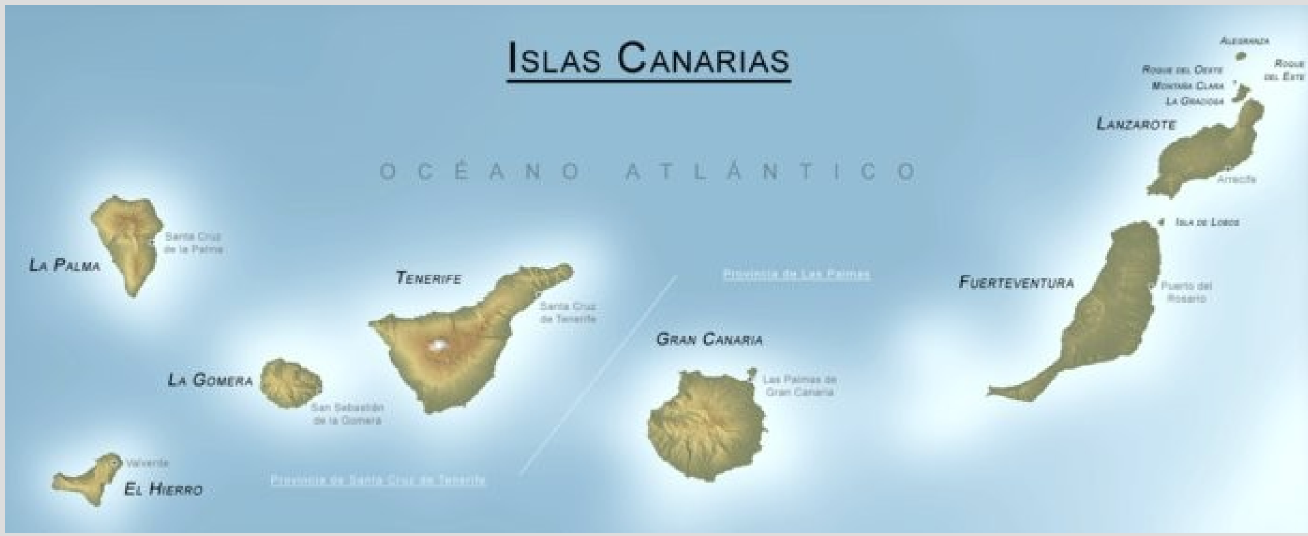
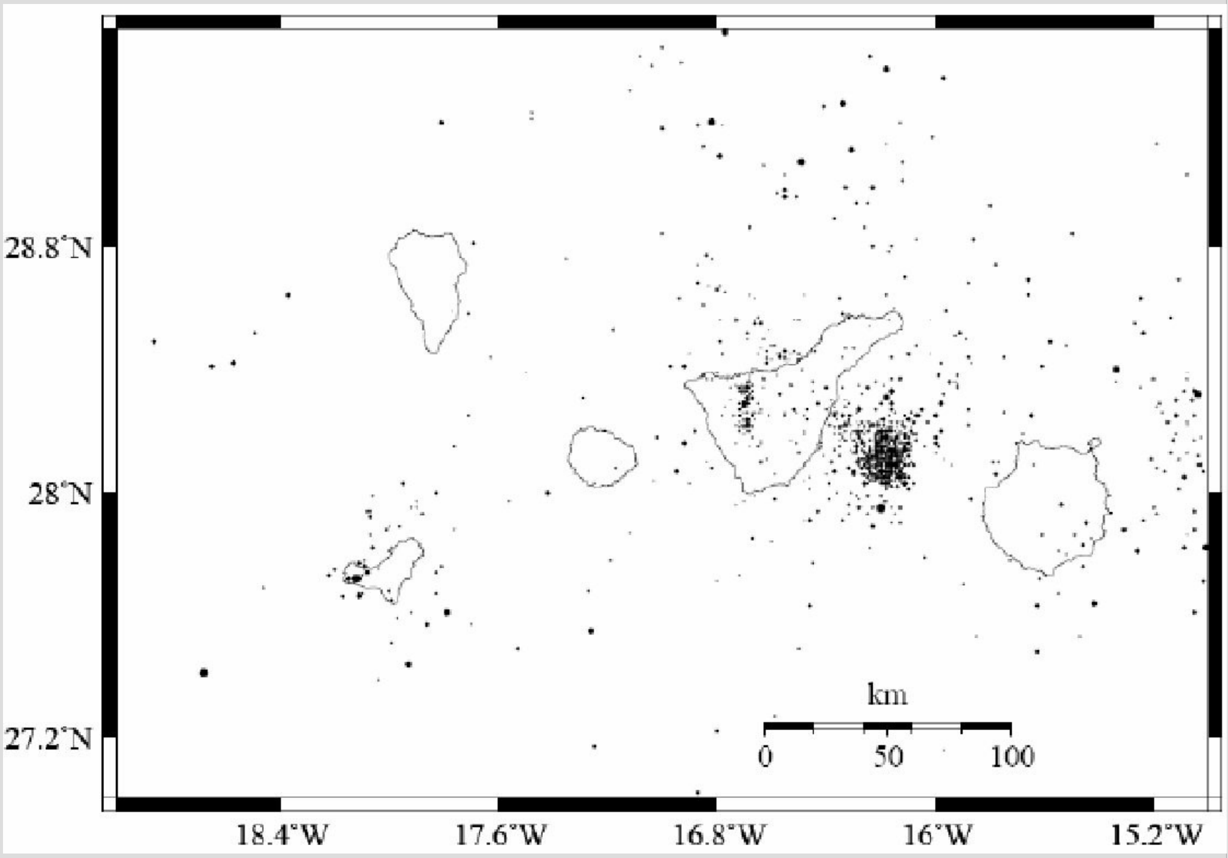
Canary Islands



- Canary Islands form a volcanic archipelago with 7 major islands with a long-standing history of volcanic activity that began more than 40 million years ago
- More than a dozen eruptions have occurred on the islands of Tenerife, Lanzarote, and La Palma since the 16th century
- Even after a century of study, its origins remain under discussion and several hypothesis are proposed, such as a hotspot or mantle plume, a region of compressional block faulting, a rupture propagating from the active Atlas Range, or a unifying model

Seismicity in the Canary Islands

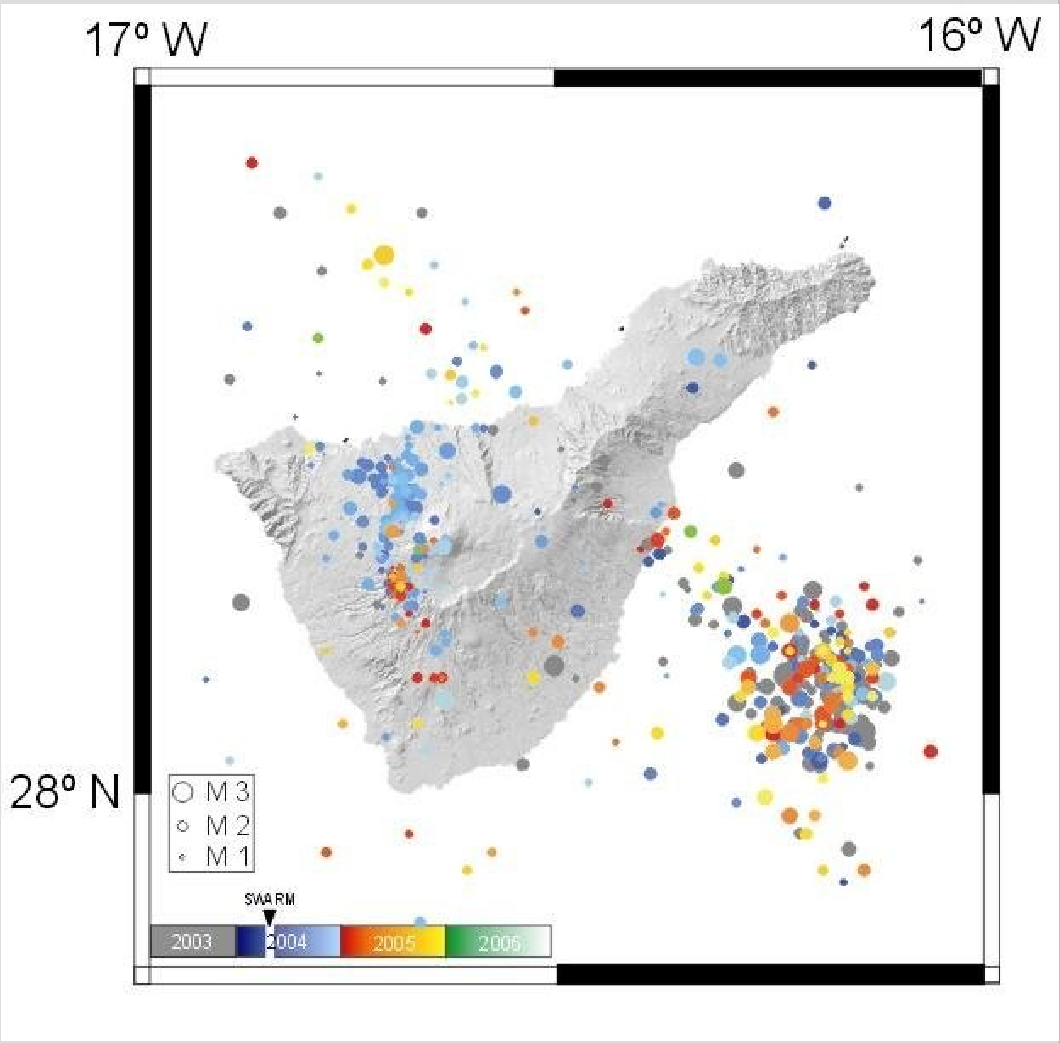
- Diffuse and disperse in most of the region
- Concentrated in an area between Tenerife and Gran canaria as well as in a line NW-SE, where there is a submarine alignment of volcanic seamounts



Prieto, et al. (2008)

Volcano-tectonic reactivation episode: 2004-2006

- Anomalous low-magnitude seismicity has been recorded since 2001 by the National Geographic Institute of Spain (IGN), but more significanty during 2004 and 2005
- From April to December 2004, 195 seismic events were located, and more than 350 to February 2006
- The total number of recorded seismics events during the period 2004-2006, including those not located, was greater than 3000



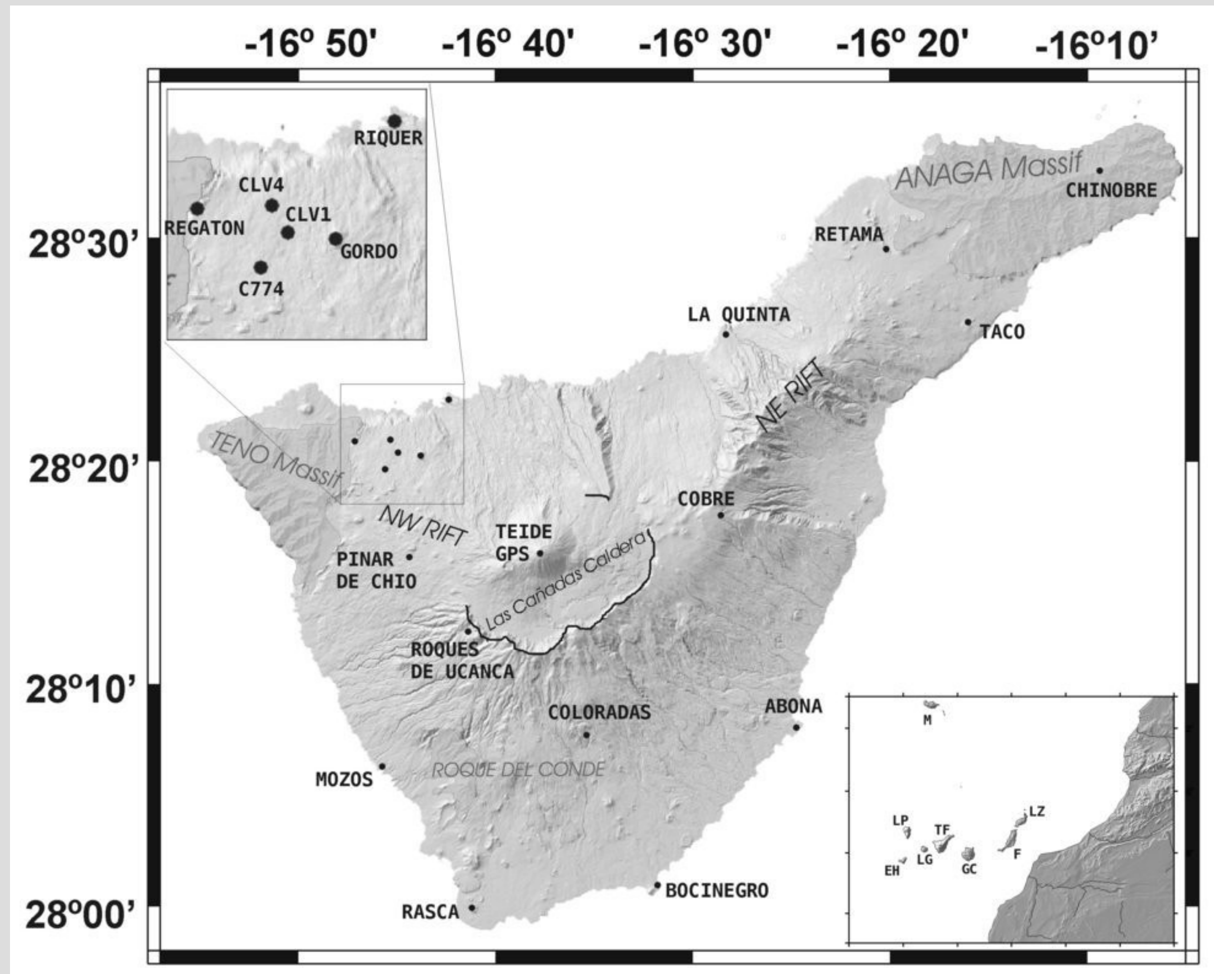
Fernández, et al. (2008b)

GPS works

6 GPS campaigns:

- Aug. 2000 (global network)
- Jul. 2001 (NW-Rift)
- Jul. 2002 (NW-Rift)
- May. 2004 (NW-Rift)
- Jul. 2005 (global network)
- Jan. 2006 (global network

2004-2006 campaigns were carried out as a response to the seismic crisis

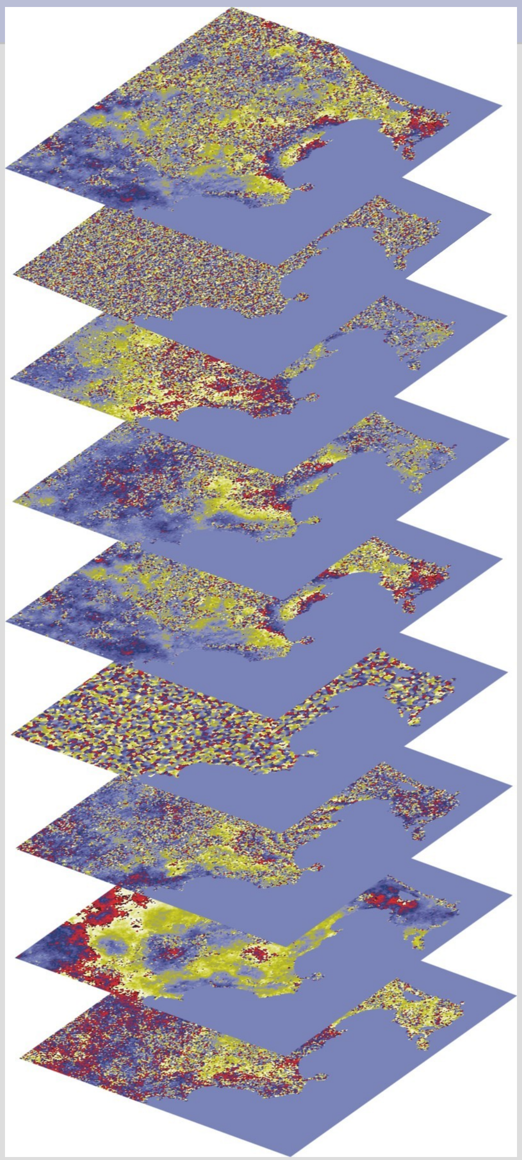


Fernández, et al. (2008b)

DInSAR technique

- Differential SAR Interferometry (DInSAR): exploits the phase difference of temporally separated SAR image pairs to measure ground deformations affecting an area of interest
- The estimated displacements represent the projection of the surface deformation on the radar line-of-sight (LOS)

SBAS approach

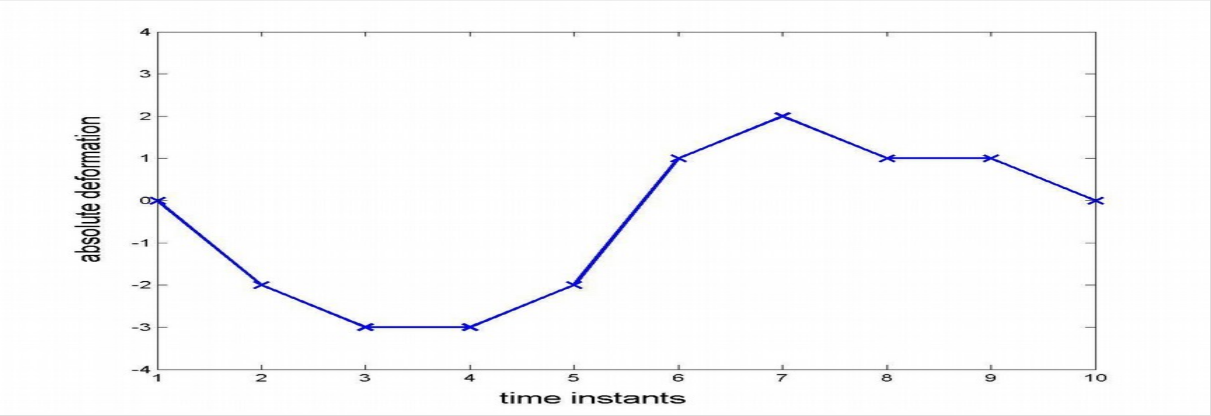


Berardino, et al. (2008)

To produce times-series deformations from a single or multi platform SAR data set by:

- Using DInSAR interferograms characterized by a "small baseline" (smaller than the critical baseline) in order to mitigate noise phenomena (decorrelation)

- Properly "linking" interferometric SAR data subset separated by large baselines. This is done by searching for an LS solution with a minimum norm constraint



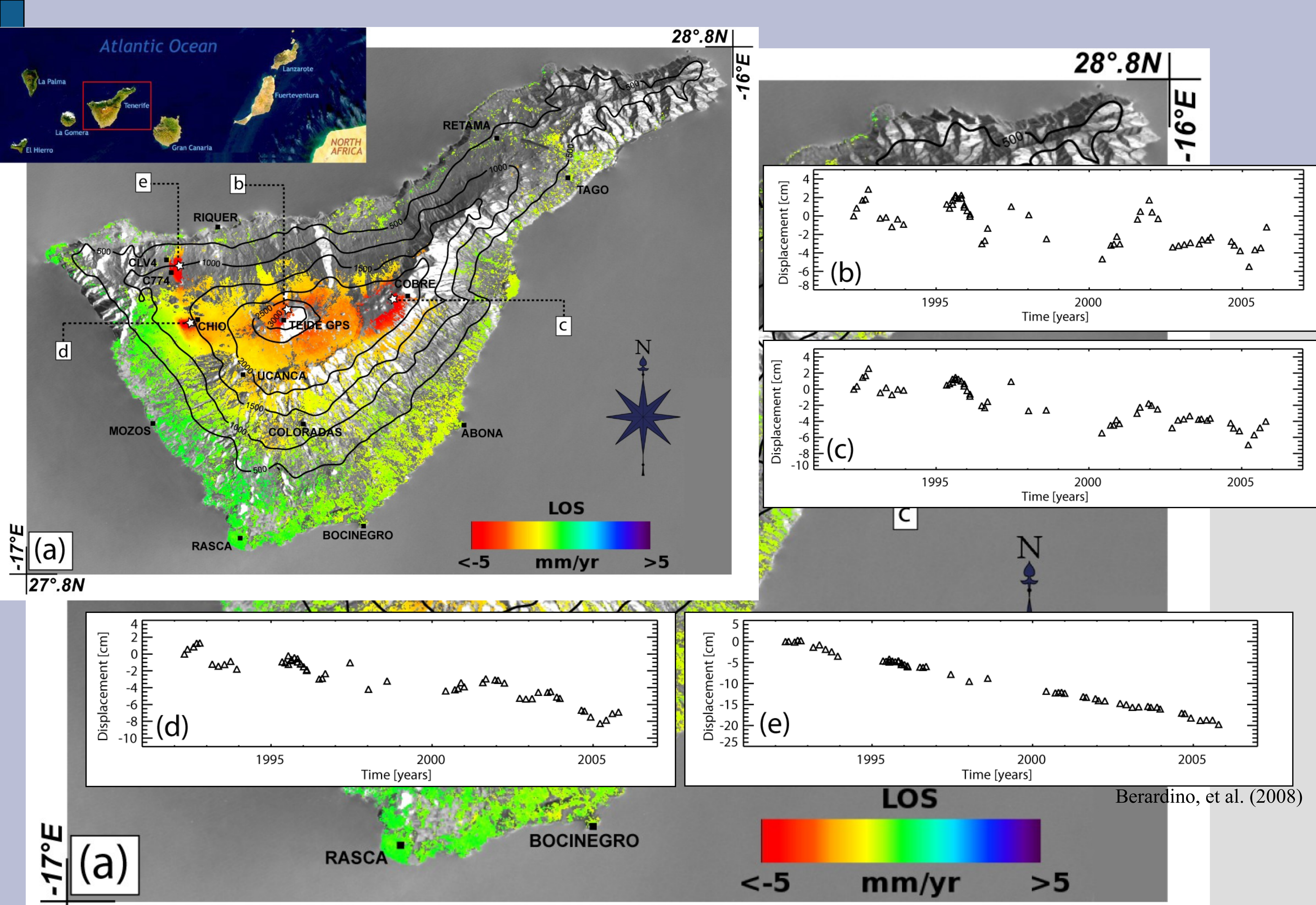
Berardino, et al. (2008)

SAR data processing

- Tenerife data analysis starting to 55 SAR images acquired in the time interval 1992-2005 by ERS 1/2 sensors. In particular, we have performed and combined via SBAS technique 182 differential interferograms with a perpendicular baseline of 400m and temporal baseline of 1500 days

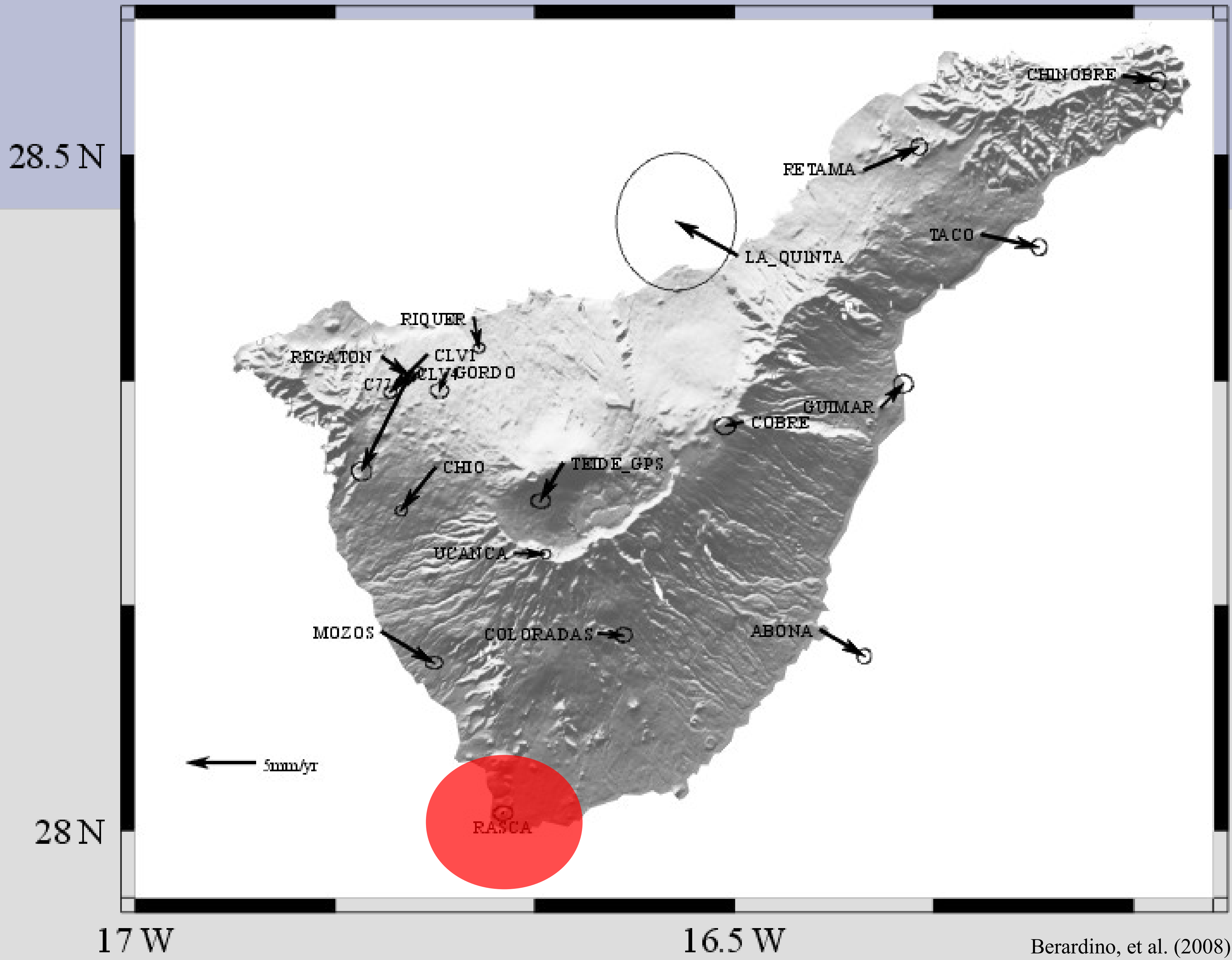
- The retrieved DInSAR deformation measurements are in very good agreement with the available GPS data

- The performed mean velocity map relevant to the coherent pixels of the island shows a significantly subsidence deformation pattern localized on the Pico de Teide and also OUTSIDE caldera region

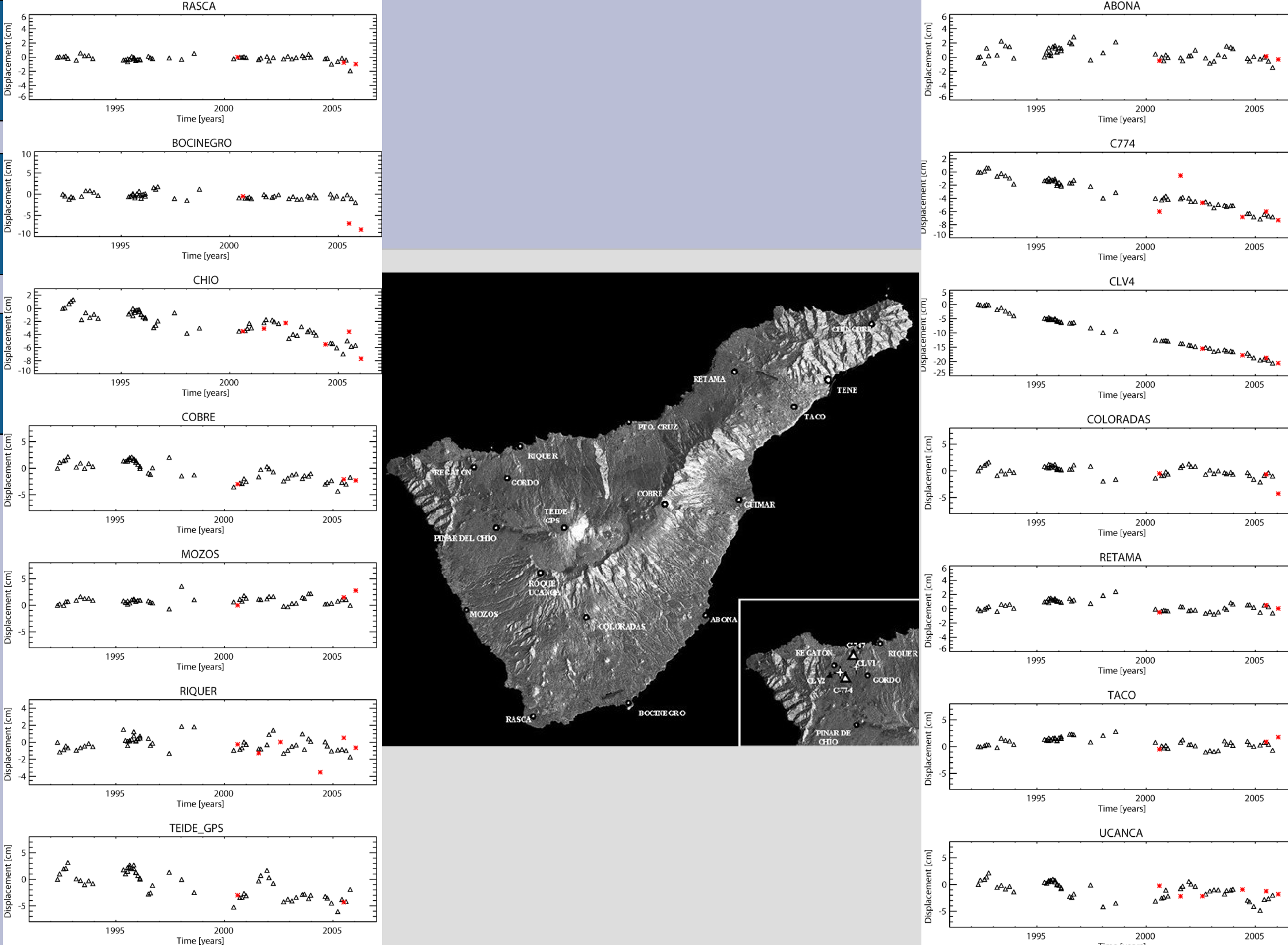


Berardino, et al. (2008)

Geocoded mean deformation velocity map (in LOS direction) computed through the SBAS-DInSAR technique and superimposed on the SAR amplitude image of the island



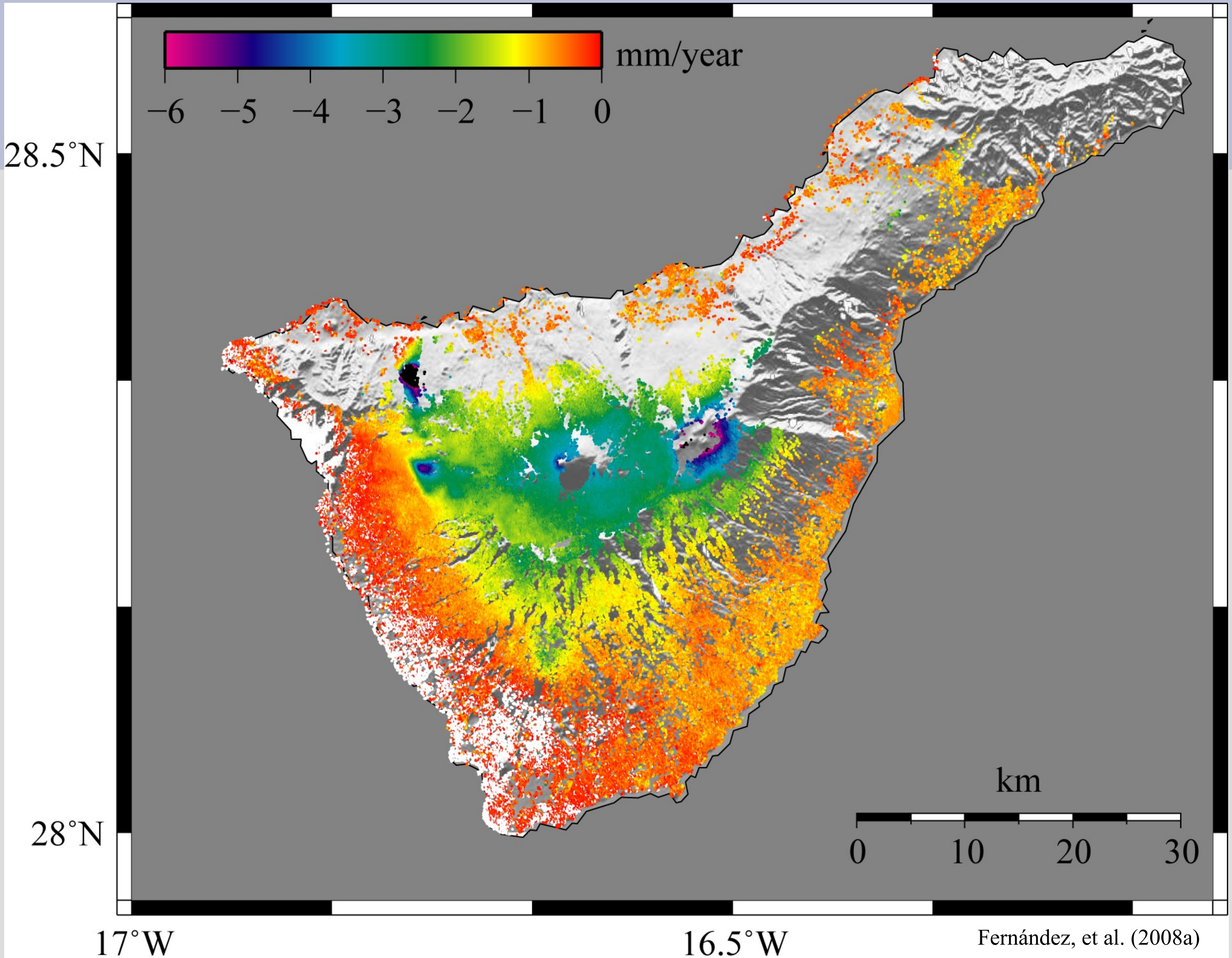
Berardino, et al. (2008)



Berardino, et al. (2008)

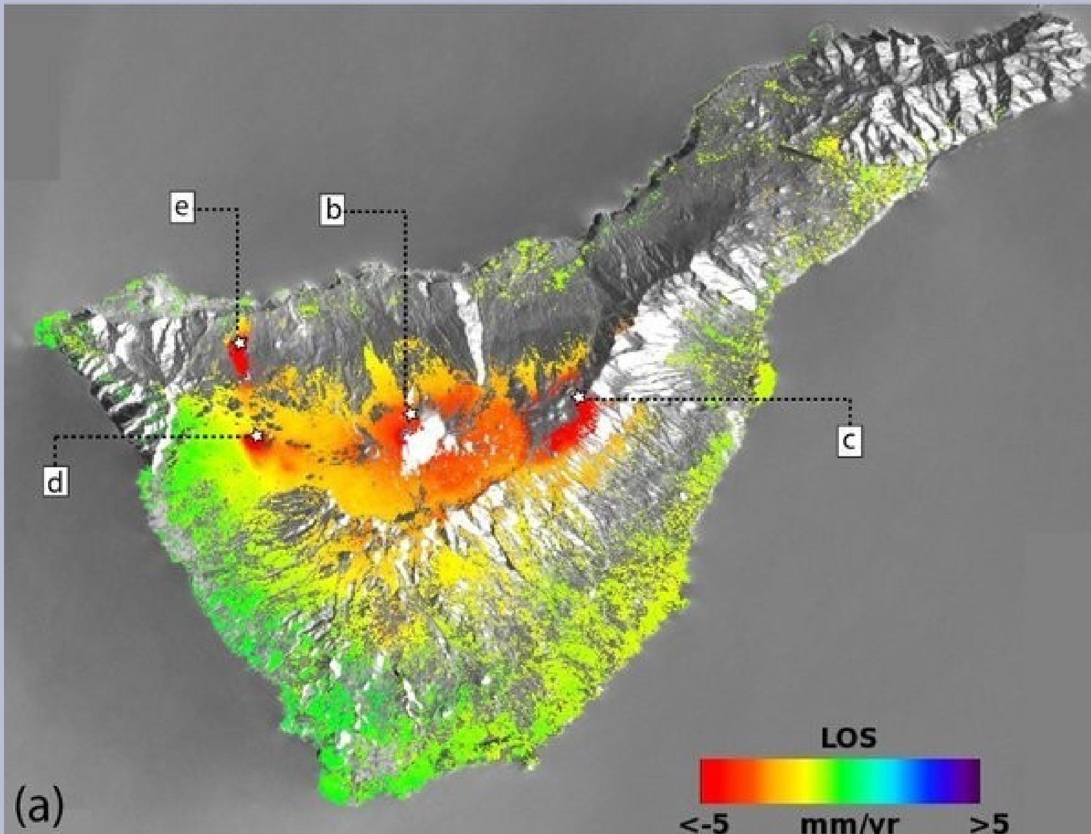
DInSAR results

- The comparison between the SAR and GPS measurements clarify that the deformation field observed on the island shows a very broad vertical component while the horizontal component is very little
- More specifically we detected an overall subsidence pattern whose signal shows a typical low magnitude, and three localized region where the general subsidence show a very significantly accelerations

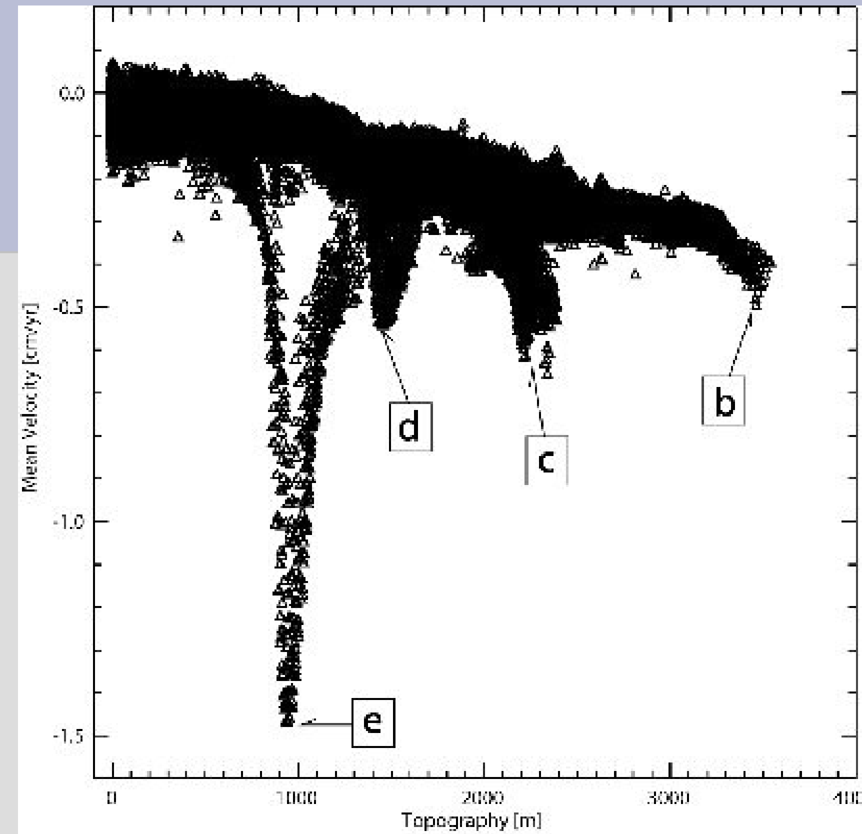


Fernández, et al. (2008a)

DInSAR results



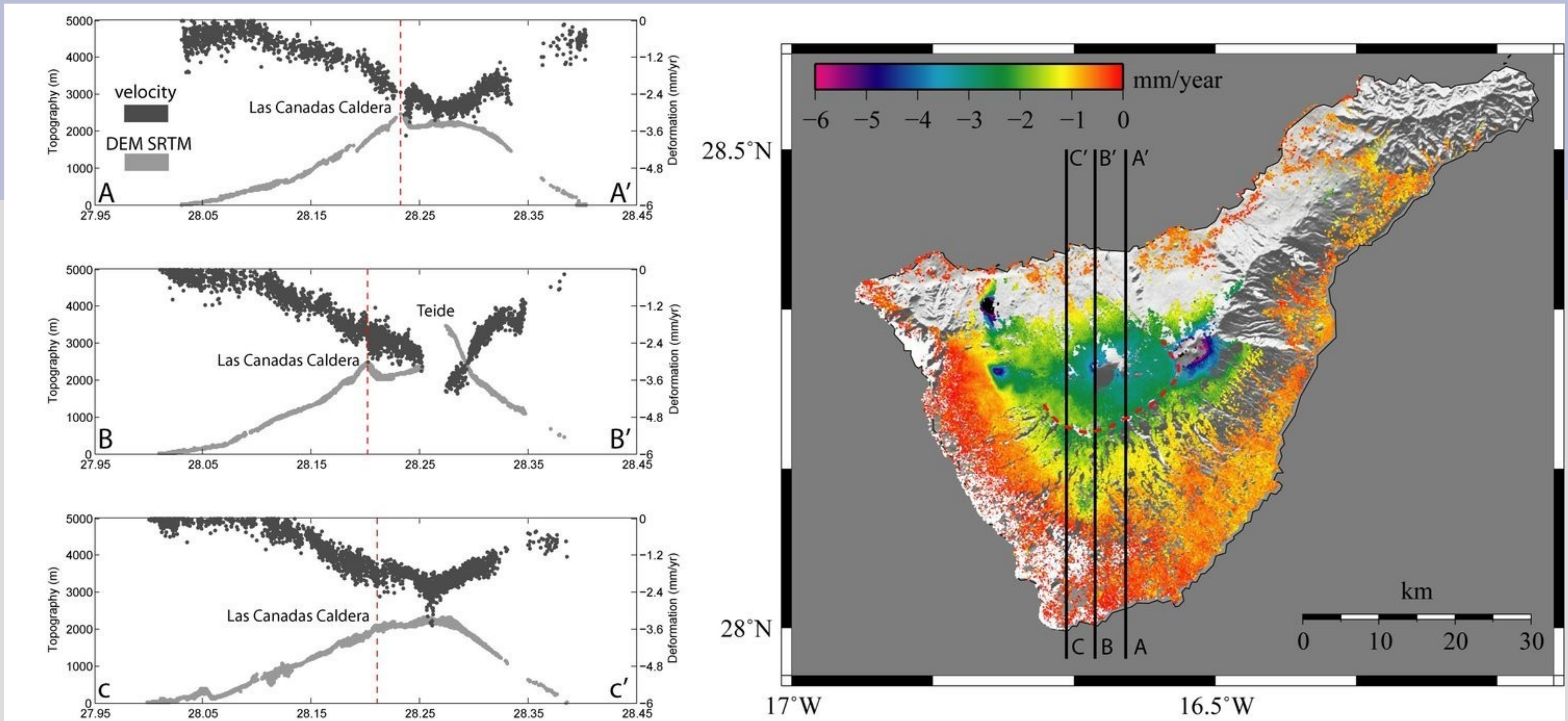
Fernández, et al. (2008a)



Fernández, et al. (2008a)

- DInSAR analysis reveals a large scale deformation anomaly that affects a much larger portion of the volcanic island beyond Las Cañadas caldera
- The measured rate of subsidence is clearly correlated to elevation

DInSAR results



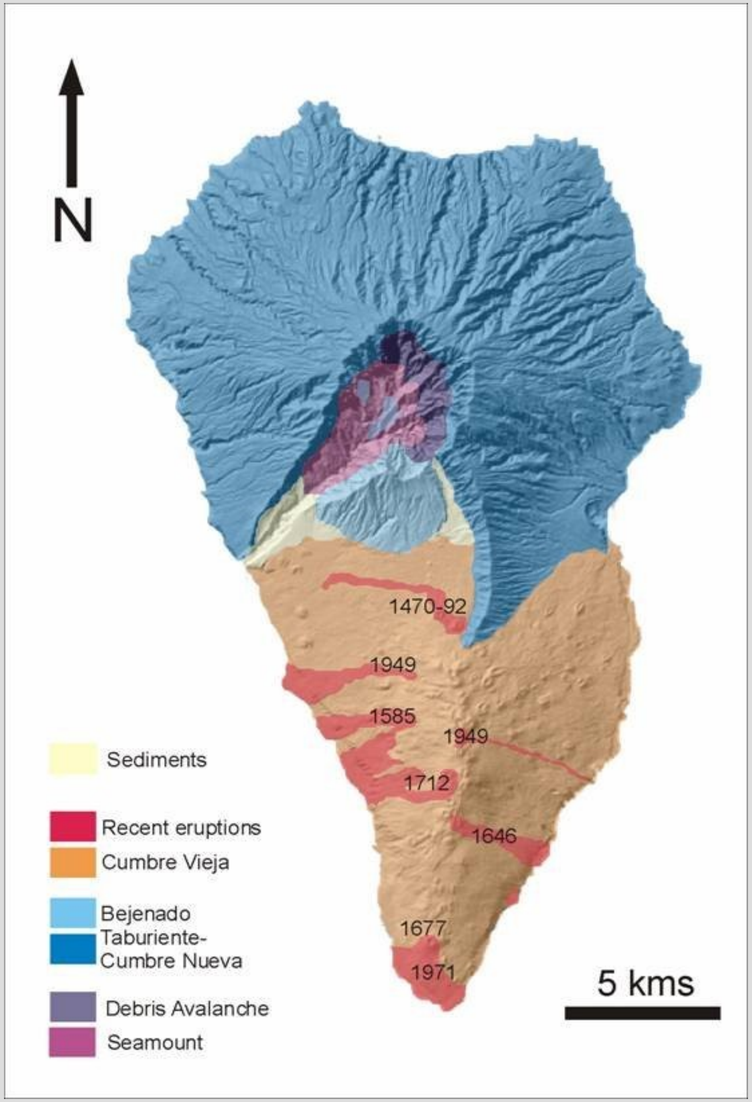
Fernández, et al. (2008a)

- This effect cannot be due to troposphere artefacts. This conclussion would imply a tropospheric induced phase component that consistently increased with time during the 14-years period of the study

- This is not a realistic hypothesis, thus, we conclude that the observed increasing rate of subsidence with elevation is a function of the geologic processes ocurring within the island

La Palma Island

- La Palma is one of the youngest and the most volcanically active in the Canary Islands
- Its geologic history is described as a sequence of southwards migrating of several partially overlapping shield volcanoes
- In the last 125kyr, volcanic activity has concentrated along a north-south elongated rift zone, called Cumbre Vieja volcano



González, et al. (2008)

Previous geodetic monitoring

- Moss el al. (1999): Geodetic network that has been used to produce three surveys using EDM and DGPS techniques in the southern part of the island (1994-1997), and have detected displacements on the same order of magnitude as the associated errors. GPS campaigns have been unsuccessful in detecting the deformation found on Teneguía volcano because the area of deformation is very small and there are no GPS stations directly in this region

- Massonet and Sigmundsson (2000); Fernández et al. (2002): Classical interferometry works. Was not precise enough to detect the displacements though to be present on Teneguía due to the magnitude of the displacements

SAR data processing

- 16 radar images acquired from descending orbits by the ERS-1/2 satellites during the 1992-2000 time interval
- Analysis of ascending data is not possible due to few available adquisitions and the steep slopes of Cumbre Vieja that prevent different estimations of the motion in the same area
- The differential interferograms are flattened using a Shuttle Radar Topography Mision DEM of the area
- 48 differential interferograms have been generated and combined characterized by a maximum perpendicular baseline value about 300 m

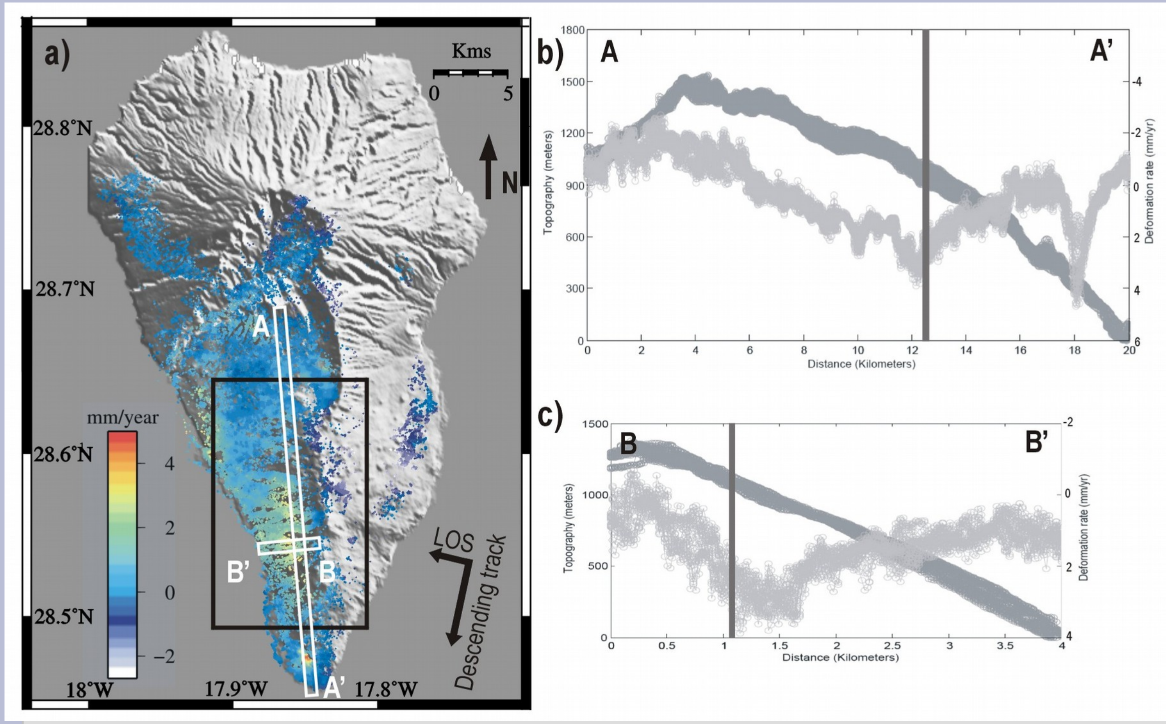
SAR data processing

- Analysis of the single interferograms did not show significant deformation, either because of the presence of turbulent and/or topographically dependent atmospheric contributions or due to low coherence by the presence of high dense vegetation

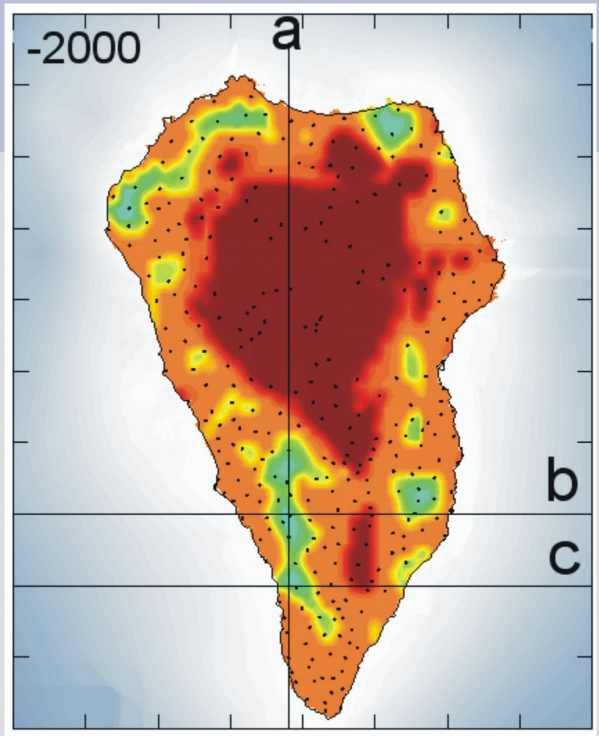
- To enhance the detections of displacements was made a stack of interferograms using every interferogram below an orthogonal baseline of 100 meters

- Stacking cannot determine deformation time series, only absolute displacement

SAR results



González, et al. (2008)



Camacho, et al. (2008)

- Results of the stacked deformation map shows two main deformation areas
- The largest magnitude deformation signal of around 5-6 mm/yr is located in the area of the 1971-Teneguía volcano
- Second, a wider subsidence area of approximately 3 mm/yr is located at the western slopes of Cumbre Vieja volcano

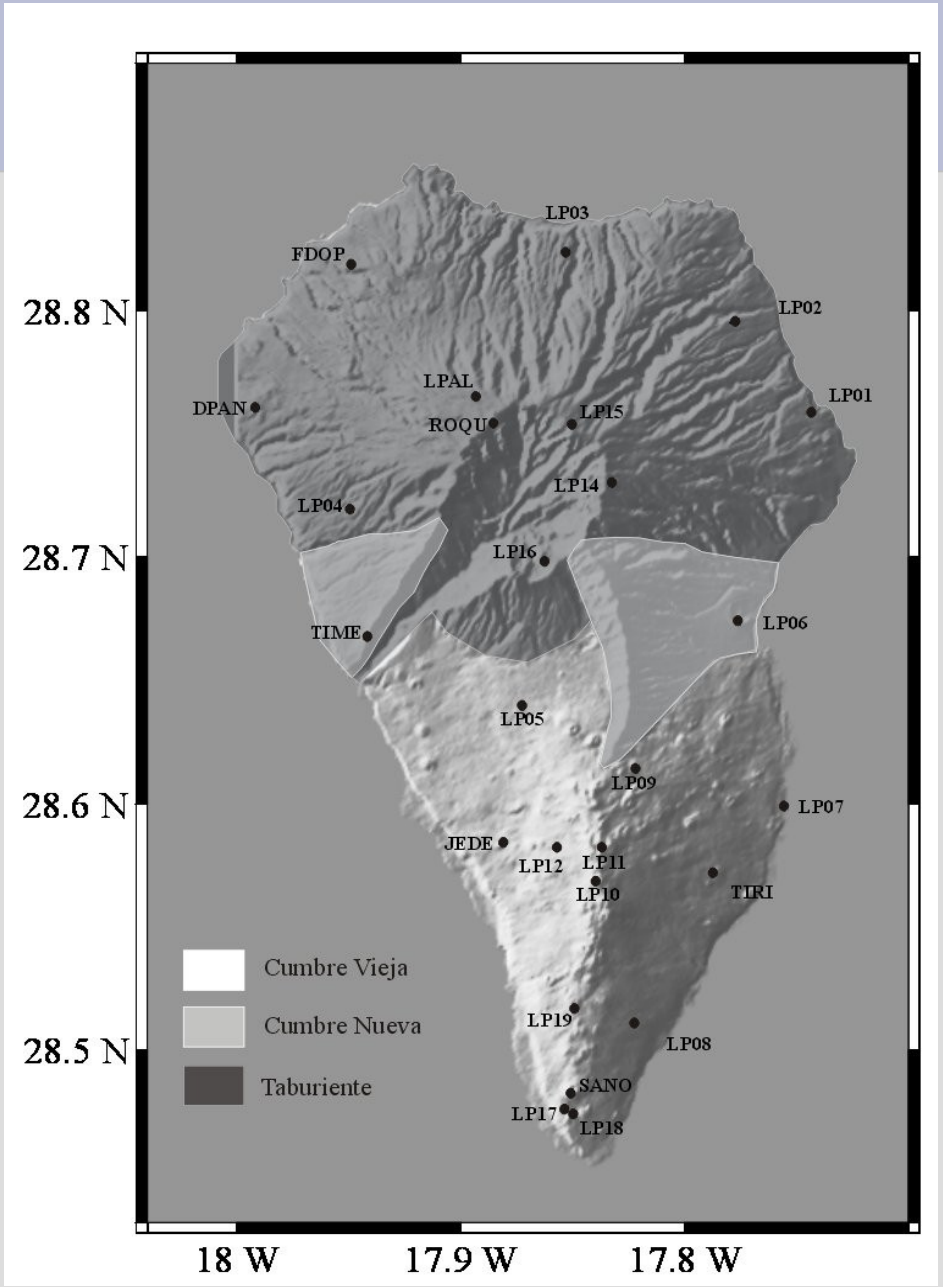
GPS works

4 GPS campaigns:

- 1994 (Instituto Geográfico Nacional)
- November 2006
- July 2007
- July 2008 (not used in this work)

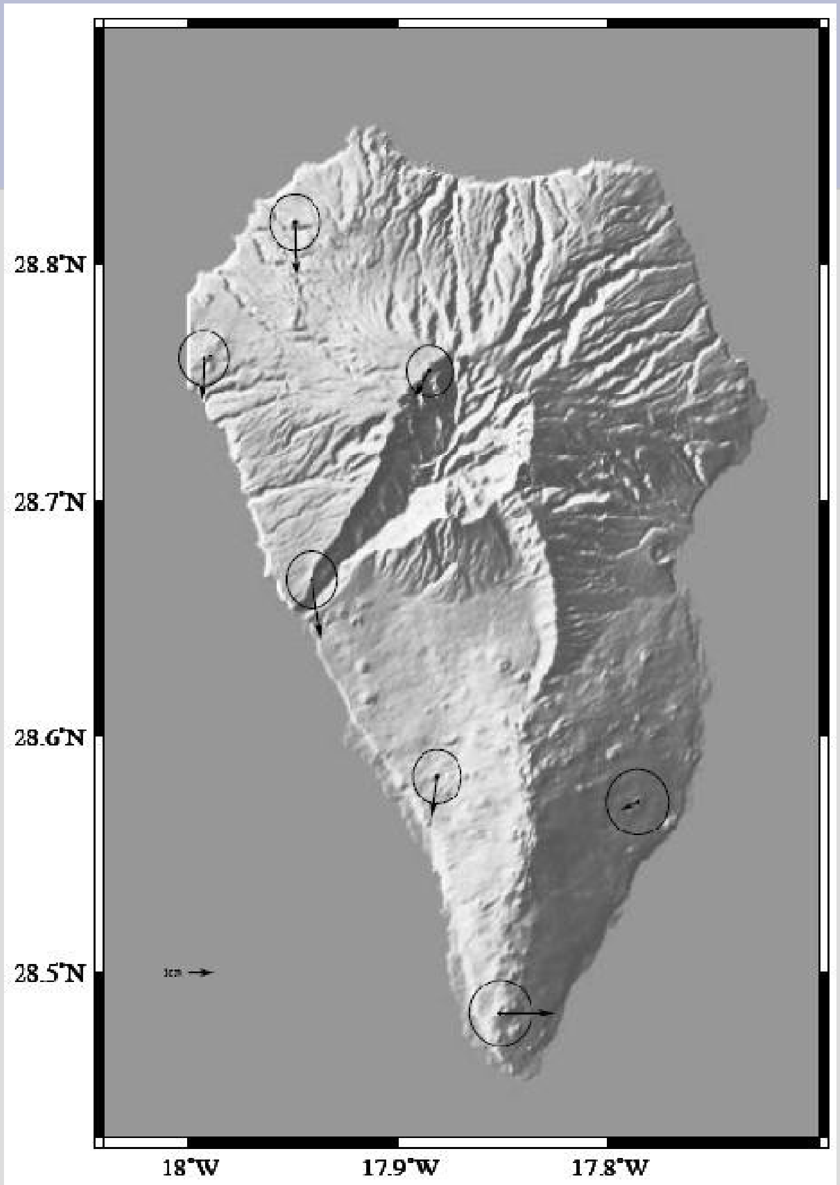
IGN network: 7 vertex

Our network: 7 (IGN) + 19 vertex



Prieto, et al. (2008)

GPS works



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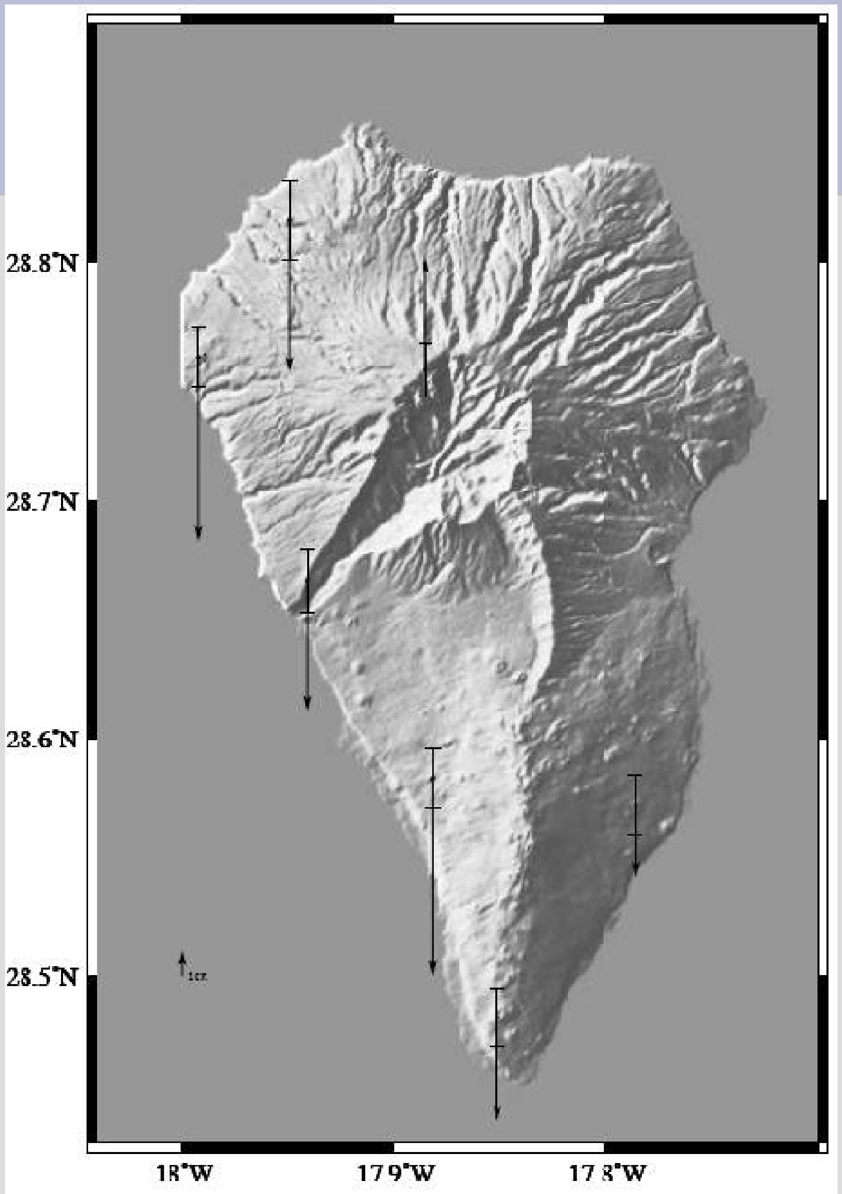
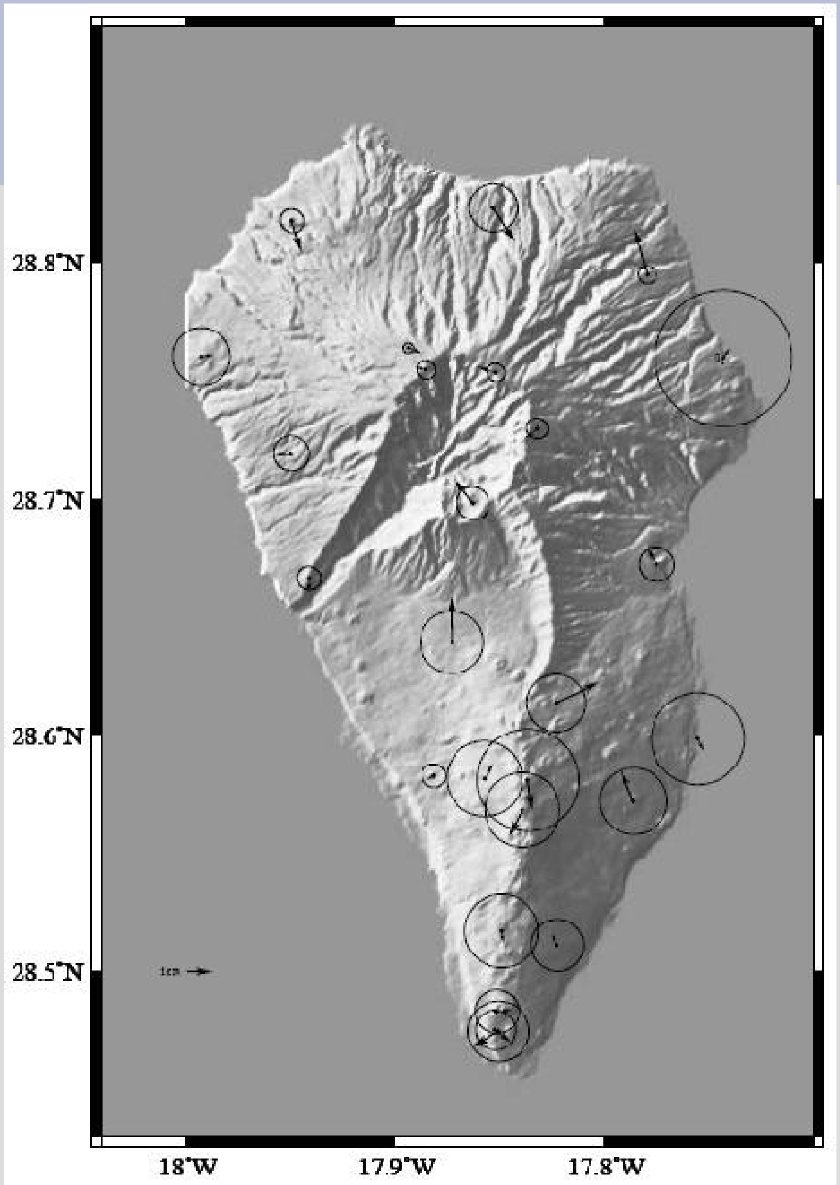


Prieto, et al. (2008)

1994-2007 GPS deformation

GPS works



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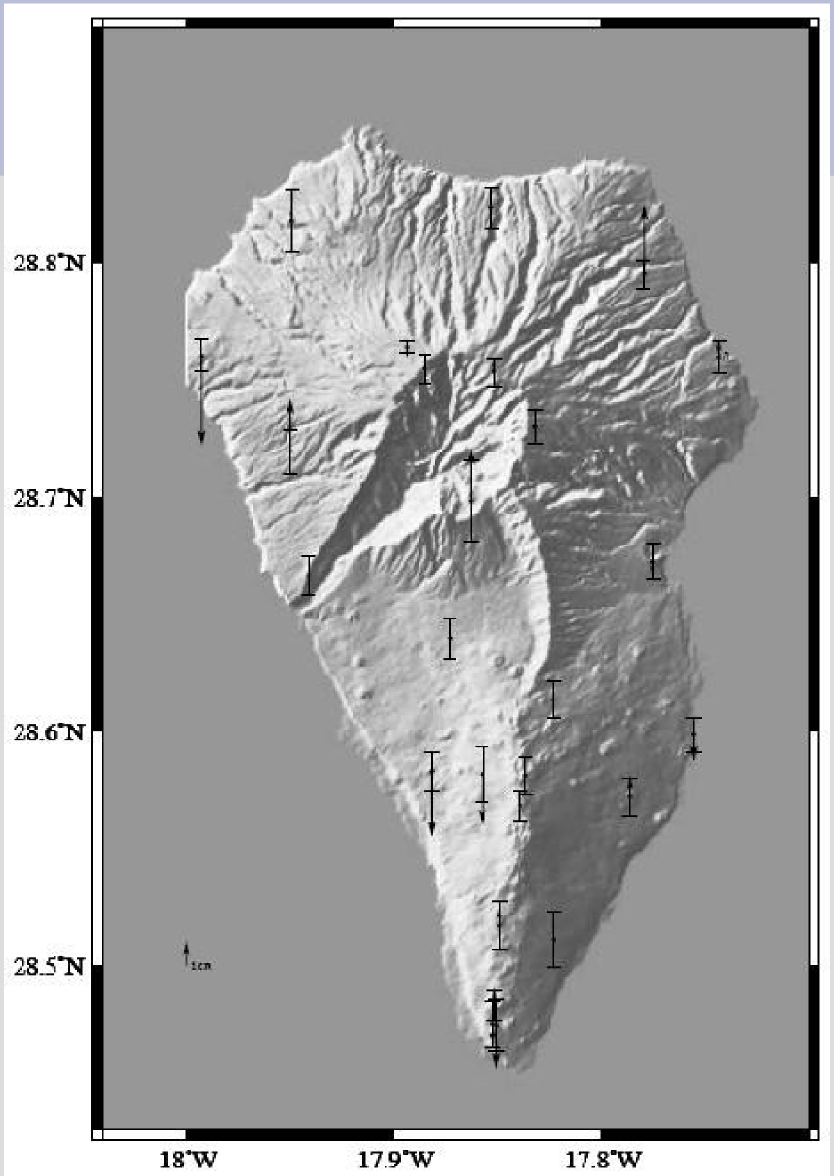

Prieto, et al. (2008)

2006-2007 GPS deformation

Conclussions

Tenerife:

- In relation to the large-scale deformation, we propose that the measured deformation is directly related to gravitational sinking of the intrusive core of the island into a weak lithosphere
- We favour this thesis, relative to that of spreading, because neither the published data on the geology of Tenerife show evidence of compressional structures around the base of the island nor the GPS data indicate significant radial displacements, which would have been present in the case of spreading
- In adition, given that the crust has been inflected under the mass of Tenerife, following Borgia (1994), we propose that the volcanic edifice is in a state of compression, which, in some volcanoes, has in the past been associated with hazardous explosive eruptions (Van Wyk de Vries and Borgia, 1996)

Conclussions

La Palma:

- Significative deformation in La Palma was detected for the first time using DInSAR processing
- Possible sources for the Teneguía area deformation are a shallow thermoelastic contraction body of heated materials and/or consolidation of lavas
- Subsidence area located at the western slopes of Cumbre Vieja volcano are in correspondence with a zone of negative mass anomaly, detected by structural gravimetric inversion

Conclussions

- We remark the potential of DInSAR data analysis to measure subtle deformation rates at volcanic areas
- Wide areas can be analyzed, and high density points with deformation values can be obtained
- In absence of clear seismic evidence of magmatic or volcano-tectonic activity, long term and slow deformation rates can be detected in both islands
- This information should be incorporated in any future evaluation of the volcanic hazard maps, as well in the development of a multidisciplinary volcano monitoring system

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